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Factors mediating the association between recurring floods and child chronic undernutrition in northern Bangladesh

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A B S T R A C T

Objectives: Although there is some evidence that flood exposure in Bangladesh and other developing countries increases the risk of chronic undernutrition in children, the underlying mechanisms are, to our knowledge, unknown. The objectives of this research are to examine the association between recurrent flood exposure and the likelihood of chronic undernutrition in children and to investigate the mediators of this association.
Methods: This cross-sectional study was conducted in the Naogaon District in northern Bangladesh. Purposive sampling was used to choose 800 children between the ages of 12 and 59 mo in equal numbers in the specified flood-affected and flood-unaffected areas: 400 children from the flood-affected area and 400 from the flood-unaffected area. The nutrition indicator height for age, expressed as *z* scores, was used to define child chronic undernutrition. Our study focused on children who have been exposed to multiple floods in the past 5 y.
Results: In our sample data, children who had experienced flooding had a 1.74-times higher chance of having chronic undernutrition (95% CI, 1.53–2.28) than children who had not experienced flooding. The mediation analyses found inadequate minimum dietary diversity, history of diarrhea, not being fully vaccinated, not using clean cooking fuel, and not having a separate kitchen contributed 19.5%, 10%, 9.8%, 14.8%, and 10%, respectively, to the flood exposure–child undernutrition association.
Conclusions: Flood exposure was found associated with the likelihood of child chronic undernutrition, and this relationship was mediated through lack of having a separate kitchen, history of diarrhea, insufficient vaccination, use of unclean cooking fuel, and poor minimum dietary diversity. Interventions to reduce the prevalence of these risk factors could contribute to reducing the disparities in child undernourishment brought on by exposure to flooding.

Introduction

Significant progress has been made in reducing chronic undernutrition in children ages <5 y over the past decade. However, Bangladesh continues to have one of the world's highest rates of child chronic undernutrition, and this condition is the leading cause of morbidity and mortality in children in the country [1]. In 2017, ~31% of Bangladeshi children were chronically undernourished [2], and undernutrition was responsible for roughly two-thirds of mortality in children ages <5 y [1].

Although biological [3,4] psychosocial [5], and socioeconomic [6–8] risk factors for chronic undernutrition in children are well understood, research into the influence of various environmental hazards has just recently begun. A flood risk is regarded as one of the environmental disasters that may have an effect on children's nutritional status. Epidemiologic research in low-income rural areas suggests that flooding increases the risk of disease in

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The data sets used and/or analyzed during this study are available from the corresponding author on reasonable request.
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children, including diarrhea [9,10], cholera [11], leptospirosis [12], typhoid fever [13], and respiratory infection [10].

Even though there are few and geographically limited data available, flood exposure has been found to have nutritional repercussions for children [14–19]. For example, a population-based survey of children ages 6 to 59 mo living in flooded and non-flooded communities in the Jagatsinghpur District of Odisha, India, discovered that cases of severe undernutrition in children were more common in the repeatedly flooded communities than in the non-flooded communities [15]. Child age, mother age, household type, water quality, and toilet facilities were found the major contributors to child stunting in the flood-affected districts of Pakistan in a cross-sectional study [18]. Another study that included 298 children ages 6 to 59 mo and was conducted in flood-affected areas of Khyber Pakhtunkhwa, Pakistan, found that the significant determinants of mid upper arm circumference–based undernutrition in the area were child age, maternal age, family size, income level, mother education, water quality, and toilet facility [19].

Bangladesh is widely regarded as one of the world's most severely flooded countries [20]. On average, regular floods inundate 21% of Bangladesh's land area, but after catastrophic floods, that proportion can reach ≤ 80% [21]. Flooding had inundated 21 districts in this country as of July 2020, affecting 3.3 million people and leaving 7 31 958 people waterlogged, causing widespread damage to agricultural production, communication and basic services infrastructure, and homestead land and housing, limiting access to safe drinking water, adequate sanitation, and food security for millions [21]. As a result, it is reasonable to suppose that children in this severely flood-affected country who are exposed to floods each year are more susceptible to undernutrition.

The association between flood exposure and the risk of chronic undernutrition in children is probably because of five sets of mediating variables: inadequate dietary and breast-feeding practices, lack of micronutrient supplementation, disease occurrence, inappropriate health-seeking behaviors, and poor living condition (indoor air pollution).

Evidence suggests that having a low dietary diversity score [22], initiating breast feeding late, [23], and lack of micronutrient supplementation [24] are associated with a higher risk of chronic undernutrition. Furthermore, due to low purchasing power, loss of agricultural production and livestock, lack of breast-feeding support capacity, and damage to communication and health services infrastructure, families in flood-prone areas are more likely to have a low dietary diversity score [25], delayed breast-feeding initiation [26], and lack of micronutrient supplementation [27].

According to research, infectious diseases, such as diarrhea and pneumonia, have also been related to chronic undernutrition in children [8,28]. Furthermore, children in flooded areas are commonly subjected to epidemics of waterborne infectious diseases [9–13] and pneumonia [10] because of lack of safe water, sanitation, and poor hygiene habits. In flood-affected communities, children are also less likely to receive oral rehydration therapy or treatment for suspected pneumonia as well as full immunization [29] due to damage to the health care infrastructure.

Aside from inadequate dietary and breast-feeding practices, lack of micronutrient supplementation, disease occurrence, inappropriate health behaviors, and poor living environments (indoor air pollution), such as using in unclean cooking fuel and not having a separate kitchen, have all been linked to undernutrition [30]. According to a study, living in flood-prone areas increases the risk of indoor air pollution due to lack of availability of clean fuel and a loss of cooking space [31].

Although there is some evidence [14–19] that flood exposure increases the likelihood of child chronic undernutrition in Bangladesh and other poor countries, the underlying mechanisms are unknown. To date, no research has been conducted to investigate the mediators that link flood risks with the likelihood of child chronic undernutrition. Understanding the mechanisms behind the association between flood exposure and the risk of chronic undernutrition in children ages <5 y will aid policymakers in developing tailored and effective nutrition intervention plans to help flood-prone children.

This study was performed 1) to examine the relationship between recurrent flood exposure and the likelihood of child chronic undernutrition and 2) to investigate the roles of inadequate dietary and breast-feeding practices, lack of micronutrient supplementation, disease occurrence, inappropriate health-seeking behaviors, and indoor air pollution in mediating the relationship between exposure to recurrent flood and the likelihood of child chronic undernutrition.

Materials and methods

We used the Strengthening the Reporting of Observational Studies in Epidemiology Checklis to report our finding.

Design and settings

This is a community-based cross-sectional study. This research was carried out in flood-affected and -unaffected villages in the Naogaon District of northern Bangladesh. Naogaon is one of the 21 districts in Bangladesh designated by the Bangladesh Ministry of Disaster Management and Relief as flood-prone areas [21]. This district is located on the floodplain of the Jamuna River and is primarily agrarian in nature, with 70% of the district's farmers small and marginal [32]. In 2020, 16 Unions of four Upazilas in the Naogaon District were hit by flooding (Atrai: 6, Dhamoirhat: 1, Manda: 4, and Raninagar: 5) [21].

A three-stage sampling approach was used to collect the data. In the first stage, three flood-affected Upazilas, namely Atari, Manda, and Raninagar, and three flood unaffected Upazilas, namely Neamatpur, Porsha, and Sapahar, were chosen at random. In the second stage, we chose two Unions at random from each of the flood-affected and -unaffected Upazilas. In the final stage, in an equal number from each of these two Unions in both the flood-affected and -unaffected Upazilas, 800 households with one child from each household were purposively selected (Fig. 1).

Sample size and study population

The households and children were chosen based on the following criteria: 1) children ages 12 to 59 mo who lived with their mothers, 2) singleton births, and 3) children who did not have major congenital defects or chronic illnesses. The information for the children was gathered from their mothers. If a household had >1 child age 12 to 59 mo, only the last-born child was chosen for an interview.

The sample size was determined using the formula: $n = Z^2P(1\text{-}P)/d^2$, considering the confidence interval at 95% (Z = 1.96), population percentage at 50% (P = 0.5), and margin of error at 5% (d = 0.05%). Here, P stands for suggested prevalence, Z for statistic related to level of confidence, n for sample size, and d for precision (matching to effect size). To reduce the effects of non-response and to increase the study's power, the sample size was further raised to 400. Thus, we intended to survey ≥ 800 children in both flood-affected and flood-unaffected areas (flood-affected area: 400 and flood-unaffected area: 400 [Fig. 1]).

Data collection

Because floods in Bangladesh normally occur in the months of July and August [21], we have gathered data 4 mo after the flood, from January 1, 2022, to February 28, 2022. We have conducted the survey 4 mo after the flood to provide the community with time to recover from the disaster and any medical procedures they may have undergone. Furthermore, for the fieldworkers' convenience, it was necessary to wait for the streets and houses to dry before conducting interviews. The questionnaires were written in English and then translated into Bangla, Bangladesh's native language. Experts and volunteers assessed the translation, and pilot research was done to validate the questionnaire.

Data quality assurance

Adequate design of our study ensured data quality, and the questionnaire was pretested on 10% of the overall sample participants (*n* = 80) who did not participate in the survey. After the questionnaires have been amended to remove any ambiguities, the final survey was administered. Two days of intense training was

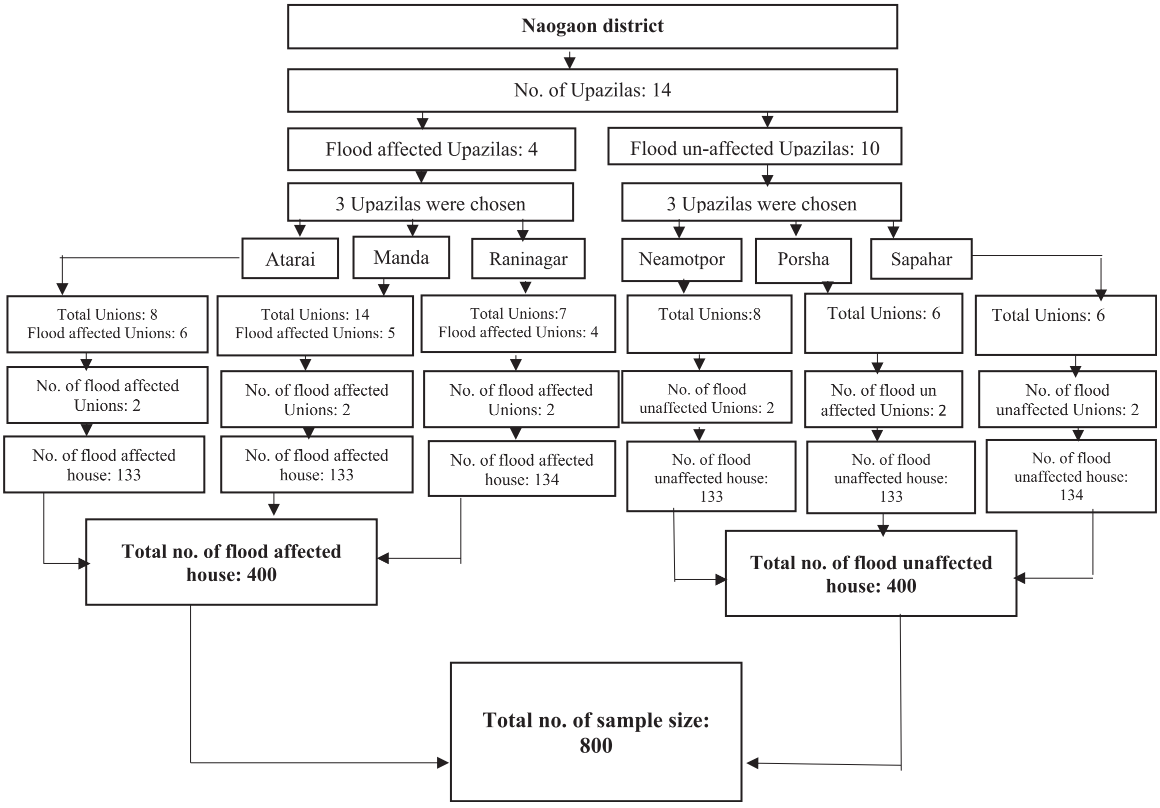

Fig. 1. Selection of the sample.

provided to the data collectors to familiarize them with the tools and processes of data gathering. Every day, the principal investigator double-checked the collected data for completeness, accuracy, and clarity. The principal investigator also kept an eye on the data collection process. Because the information was gathered from the mothers of the children, 10 fully qualified and experienced female field researchers were hired to conduct all household visits.

Measuring variables

Outcomes

The nutrition indicator, height for age *z* score (HAZ), was used to define child chronic undernutrition. We looked at HAZs because they indicate cumulative growth and are more likely to be accurate over time than shorter-term weight-for-height *z* scores. Recumbent length was recorded for children ages <2 y, and standing height was measured against a flat wall using a ruler pressed against the head crown and a measuring tape for all other children. HAZ was categorized based on the *z* scores of age and sex-specific parameters that were extracted from the 2000 Centers for Disease Control and Prevention data tables. [33] The *z* scores were calculated, using the LMS method, where

$$z = \frac{\left[\left(\frac{\text{Value}}{\text{M}}\right)^{\text{L}}\right] - 1}{\text{L} \times \text{S}},\ \text{L} \neq 0$$

In the above equation, *Value* corresponds to the participant's height, and the *L*, *M*, and *S* values correspond to parameters extracted from the 2000 Centers for Disease Control and Prevention percentile data tables. A child was chronically undernourished if HAZ < -2 SD [33]. A binary variable was created to define whether chronic undernutrition exists.

Exposure

Our study focused on children who have been exposed to multiple floods in the past 5 y.

Mediators

The conceptual model (Fig. 2) underlying the present study suggests that the link between flood exposure and the likelihood of chronic undernutrition in children, according to the United Nations Children's Fund framework [34], its adaptation in the *Lancet* maternal and child nutrition series [35], and previous practices [36,37], is most likely due to five sets of mediating variables: 1) inadequate dietary and breast-feeding practices; 2) lack of micronutrient supplementation; 3) disease occurrence; 4) inappropriate health-seeking behaviors; and 5) poor living conditions (indoor air pollution) (Fig. 2).

Dietary and breast-feeding practices. Within a 24-h period, dietary diversity was assessed using the following seven food groups: 1) cereals, roots, and tubers; 2) legumes and nuts; 3) dairy products; 4) flesh foods (meats, fish, and poultry); 5) eggs; 6) vitamin A–rich fruits and vegetables; and 7) other fruits and vegetables [38]. The dietary diversity score, which ranges from zero to seven, was calculated by adding the group scores, with zero representing no consumption of any of the food items and seven representing the highest amount of diet diversification. Children who consumed $\geq$ 4 food categories in the 24 h preceding the interview were deemed to have met the bare minimum dietary diversity requirements. As a result, the variable was classified into two groups: adequate minimum dietary diversity requirements and inadequate minimum dietary diversity requirements.

Breast-feeding initiation was divided into two categories: breast feeding initiated in $\leq$1 h of birth and breast feeding initiated $>$1 h of birth. Breast feeding was considered delayed if it $>$1 h after birth [2].

Micronutrient supplementation. A binary variable was created to indicate whether a child was receiving vitamin A supplements. A binary variable was created to indicate if the child's household uses iodized salt.

Disease occurrence. The occurrence of infectious disease in children was defined by the following two conditions: acute diarrhea was defined as passing watery or soft stools $\geq$ 3 times in 24 h during the 2 wk prior to the interview [37], and an episode of acute respiratory infection (ARI) was defined as having a cough/cold or breathing difficulty during the 2 wk prior to the interviews [37].

Health-seeking behaviors. Seeking treatment for the purpose of finding a remedy for the children's common childhood illness, such as diarrhea or ARI, and receiving complete immunization was considered a health-seeking behavior. The United Nations Children's Fund Multiple Indicator Cluster Survey [39] and the Demographic and Health Surveys [2] questions were reviewed in the development of the health-seeking behavior questionnaires. Mothers were questioned about their frequency of giving their child oral rehydration therapy if they had experienced diarrheal illness, and their responses were divided into two categories: 1) always

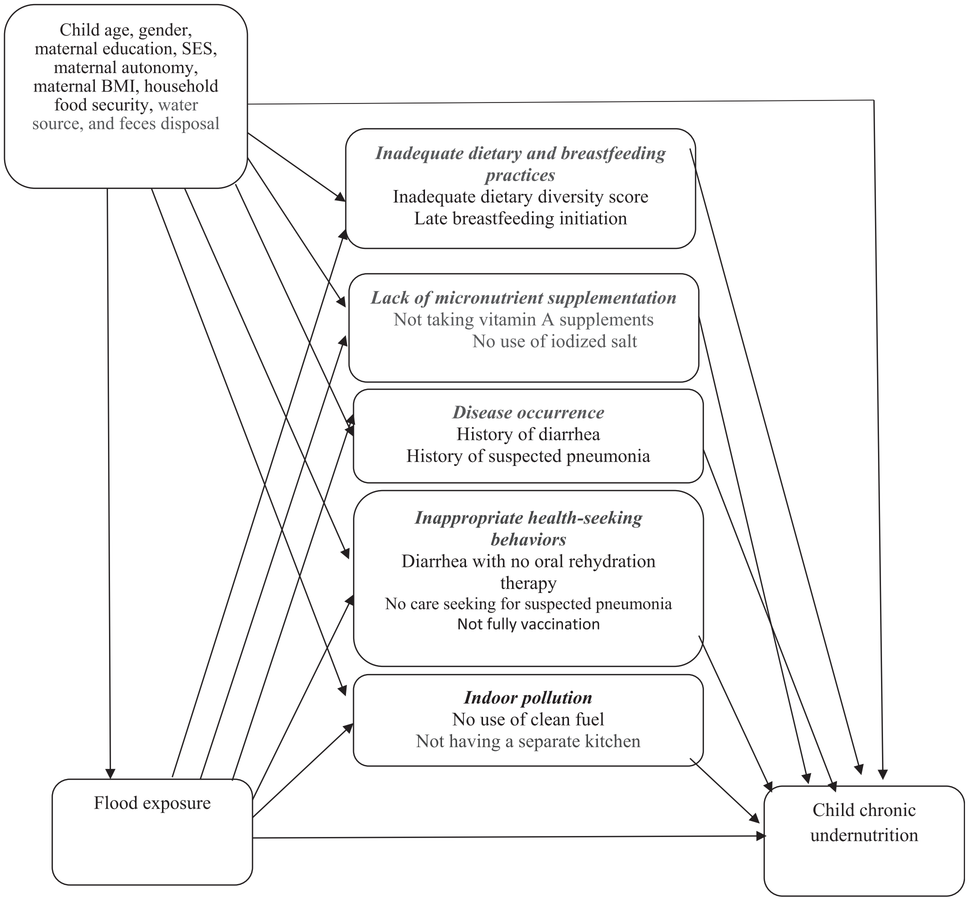

Fig. 2. Pathways assumed for the domains of mediators between exposure to flood and child chronic undernutrition. BMI, body mass index; SES, socioeconomic status.

and 2) seldom or never used. Additionally, mothers were questioned about if they had ever sought treatment for their child if they had ever experienced ARI. The answers were sorted into two categories: yes or no. If a child received one dose of bacille Calmette-Guérin; three doses of diphtheria, pertussis, and tetanus; four doses of poliomyelitis; and one dose of measles vaccinations, they were deemed completely vaccinated [40].

Indoor air pollution. The two types of cooking fuels taken into consideration in this study were clean cooking fuels and unclean cooking fuels. Wood; agricultural by-products, residues, and wastes; straw, shrubs, and grass; animal dung; kerosene; coal; lignite; and charcoal were classified as unclean cooking fuels, while electricity, liquefied petroleum gas, and biogas were classified as clean cooking fuels [30]. Cooking practices were divided into two categories: cooking in or with a separate kitchen and cooking without a separate kitchen. Cooking in the house but in a distinct kitchen was referred to as a separate kitchen. Cooking in the house but not in a separate kitchen, on the other hand, implied cooking in the house without a separate kitchen.

Covariates

We considered several sociodemographic and household-related covariates that are empirically and theoretically linked to flood exposure and the likelihood of child chronic undernutrition: child age, child sex, maternal education, maternal body mass index (BMI), maternal decision-making autonomy, food security, water sources, and stool disposal. The age of the child was divided into three categories: 12 to 23 mo, 24 to 35 mo, and 36 to 59 mo.

The maternal educational level was described according to Bangladesh's formal education system: no education (0 y), primary (1–5 y), or secondary or higher education (≥6 y).

The following questions were asked to gather data for measuring women's decision-making autonomy: 1) Who has the final say when large purchases for the house are made? 2) In terms of the woman's personal health care, who has the final say? and 3) Who has the final say over visits to family or relatives? The answers to each of these questions were coded as follows: 1) respondent, 2) respondent and husband or partner jointly, 3) respondent and someone else, 4) husband or partner, or 5) someone else in the house. To assess a respondent's autonomy from these responses, binary variables were created for each of the questions. Responses 1, 2, and 3 were merged into a single category of having decision-making power; and responses 4 and 5 were merged into a single category indicating no decision-making power.

Mothers' weight in kilograms divided by their height in meters squared yields their BMI. A cutoff point in the BMI of 18.5 kg/m^2 was used to define maternal chronic undernutrition as recommended by the World Health Organization for adult populations from the Indian subcontinent [40]. Mothers with a BMI of ≥25 kg/m^2 were overweight or obese, while those with a BMI of ≥30 kg/m^2 were considered obese [41]. The wealth index was built by assigning wealth scores on the basis of 24 selected household assets, such as the number of family members; floor, wall, and roof materials; kind of cooking fuel; refrigerator; motorcycle; and others, using principal component analysis [42]. Households were sorted into terciles based on their weighted wealth scores; each tercile was assigned a rank ranging from 1 (poor) to 3 (rich), and respondents were rated according to the total score of the household in which they live. The standardized Household Food Insecurity Access Scale questionnaire developed by Food and Nutrition Technical Assistance initiative of United States Agency for International Development was used to measure household food security status [43]. We used a binary variable for household food security status in our analysis: food secure or food insecure.

If a home has access to water piped into the dwelling, yard, or plot; a public tap or standpipe; a tube well or borehole; a protected well or spring; rainwater; or bottled water, it was regarded as having safe water sources; otherwise, it was deemed unsafe [44]. If a child uses a toilet or latrine and feces are normally flushed or rinsed into the toilet or latrine or buried, the household was regarded as having safe feces disposal; otherwise, it was considered unsafe [45].

Statistical analyses

To summarize the characteristics of the participants, we used descriptive statistics. To assess the association between exposure to flood and the likelihood of child chronic undernutrition, a binary logistic regression model was fitted for our binary outcome. We checked the model for multicollinearity by examining variance inflation factors. The odds ratios (ORs) in the binary model were estimated to assess the strength of the associations, with 95% CIs defined as the benchmark for significance testing. All the covariates were entered simultaneously into the multiple regression model.

We applied the binary result version of the Baron and Kenny approach [46] to investigate mediation of the factors to binary child chronic undernutrition by flood exposure. The Stata binary_mediation command was used to compute the direct, indirect, and total effects in the applied model. We used logistic regression models to evaluate the influence of binary exposures (exposure to flood versus no) on each mediator (binary), adjusted by covariates to test mediation with our dichotomous outcome (child chronic undernutrition or not). The results were presented as adjusted ORs (AORs) with 95% CIs created from 500 bootstrapped samples. The proportion of the indirect effects that were mediated by the mediators were calculated using the following formula:

$$\text{Proportion mediation} = \log(\text{AORIE})/\log(\text{AORTE}) \times 100\%$$

where *IE* represents the indirect effect and *TE* represents the total effect. All statistical analyses were conducted using Stata version 14 (Stata Corp., College Station, TX).

Ethical considerations

Approval was obtained from the Ethical Review Committee of Institute of Biological Sciences, University of Rajshahi (approval no. 108/327/IAMEBBC/IBSc), Bangladesh, and was planned and conducted in accordance with the Declaration of Helsinki. All participants were informed about the study's aims, risks, and benefits before beginning the interview. Patients' confidentialities were ensured, and informed consent was acquired both in writing and orally (for illiterate respondents) from the mothers of the children. For the COVID-19 pandemic situation, we took all mandatory measures (based on both national and global guidance) to protect staff members and participants.

Results

Descriptive statistics

Table 1 displays sociodemographic, household, and anthropometric characteristics; inadequate dietary and breast-feeding practices; lack of micronutrient supplementation; disease occurrence; inappropriate health-seeking behaviors; and indoor pollution–related characteristics, according to exposure to flood and non-flood scenarios. In all, 800 children were enrolled in the study. In both the flooded and non-flooded sample data, > 50% of the children were between the ages of 12 and 35 mo. In all areas, the proportion was roughly split equally between male and female patients. Only ~20% of mothers of children have preprimary education; however, the percentage is greater in flood-affected areas (25.8%) than in non-flooded areas (13.8%).

Regarding the status of food insecurity in households, 43.7% of households reported being food insecure. This percentage was greater in the data from the flooded sample (55%) than the non-flooded sample (32.2%). Compared with non-flooded samples, the proportion of sources of unsafe waters and feces disposal is higher in flooded sample data.

In our sample data, the prevalence of child chronic undernutrition was 35.1% overall, but it was substantially higher (41.3%) for children living in flood-affected areas compared with children from non–flood-affected areas (29%). In our sample data, the prevalence of low birth weight (<2500 g) was 17.5%, and the percentage was considerably higher for children from flood-affected areas (18.8%) than for children from non–flood-affected areas (16.3%). According to our sample data, 66.6% of children meet the required minimum dietary diversity; however, this percentage was considerably lower for children from flood-affected areas in comparison with children from non–flood-affected areas. Children in flood-affected areas received substantially lower vitamin A capsules and started breast feeding later than children in non–flood-affected areas (Table 1).

In comparison with children from non–flood-affected areas, the proportion of children with diarrhea and ARI was greater in flood-hit areas. Children affected by floods were less likely to receive treatment for childhood illnesses than children who were not affected by floods. In our sample data, the prevalence of completed vaccine coverage was 79.6%; however, it was lower for children living in flood-affected areas (71.5%) than in non-flood-affected areas (87.8%). Compared with non–flood-affected households, households with flood-affected children were more likely to use unclean cooking fuel and lack a separate kitchen (Table 1).

Multivariate analyses

A multivariate analysis of factors, such as flood exposure, dietary and breast-feeding habits, micronutrient supplementation, disease occurrence, health-seeking behaviors, indoor pollution as potential mediators, and additional sociodemographic factors linked to child chronic undernutrition, is presented in Table 2. Children who had experienced flooding had a 1.74-times higher chance of having chronic undernutrition (95% CI, 1.53–2.28) than children who had not experienced flooding. Children's chances of developing chronic undernutrition increase as they get older. When comparing mothers with preprimary or no education to mothers with secondary or higher education, the likelihood of child undernutrition was reduced by 0.76 (95% CI, 0.69–0.84) and 0.61 (95% CI, 0.52–0.70) times, respectively.

The odds of chronic undernutrition were 0.83-times (95% CI, 0.73–0.94) and 0.68-times (95% CI, 0.59–0.79) lower in children belonging to the middle or high SES than low SES group. Unsafe faces disposal was associated with a 0.74-times lower likelihood of child chronic undernutrition compared with their counterparts. Food-insecure households were associated with lower likelihood of having undernourished children. The increased chance of having undernourished children was linked to maternal chronic undernutrition and low birth weight (<2500 g). The probabilities of having undernourished children were lower when households used idolized salt and had an adequate minimum dietary diversity score (Table 2).

Children who experienced diarrhea were 1.15-times more likely to experience chronic undernutrition. Comparing children who had received all recommended vaccinations with their opposite counterparts, the risk of developing chronic undernutrition was 0.87-times (AOR = 0.87; 95% CI, 0.81–0.94) lower. When compared with opposite counterparts, having a separate kitchen and using clean cooking fuel reduced the likelihood of undernutrition in children by 0.85 and 0.85 times, respectively (Table 2).

Table 3 lists the direct and indirect effects in the applied model and percentage of mediation by the various potential mediators on the association of exposure to flood and the likelihood of child chronic undernutrition. The mediation analyses found a significant direct effect in the model of exposure to flood and the likelihood of child chronic undernutrition with AOR = 1.09 (95% CI, 1.06–1.13). The analyses also found that inadequate minimum dietary diversity, history of diarrhea, not being fully vaccinated, not using clean cooking fuel, and not having a separate kitchen significantly mediate the relationship between exposure to flood and the likelihood of child chronic undernutrition. Corresponding AORs = 1.08 (95% CI, 1.04–1.13), 1.04 (95% CI, 1.03–1.07), 1.04 (95% CI, 1.01–1.07), 1.06 (95% CI,1.04–1.08), and 1.04 (95% CI, 1.03–1.07), respectively.

Considering the total effect in the model of exposure to flood and the likelihood of child chronic undernutrition, the direct effect in the model explained ⍰20.8% (95% CI, 16.8–23.8), whereas the remainder of the indirect effect in the model operating via inadequate minimum dietary diversity, history of diarrhea, not being fully vaccinated, not using clean cooking fuel, and not having a separate kitchen

Table 1
Descriptive statistics of sociodemographic, household, anthropometry, dietary, and breast-feeding practices; micronutrient supplementation; disease occurrence; health-seeking behaviors; and indoor pollution–related characteristics, according to flood and non-flood exposure (n = 800)

Characteristics	Flooded (n = 400)		Non-flooded (n = 400)		Total (n = 800)	
	n	%	n	%	n	%
Sociodemographic						
Child age, mo						
12–23	111	27.7	101	25.3	212	26.5
24–35	95	23.8	107	26.7	202	25.3
36–47	91	22.8	93	23.2	184	23.0
48–59	103	25.7	99	24.8	202	25.2
Child sex						
Female	196	49.0	191	47.8	387	48.4
Male	204	51.0	209	52.2	413	51.6
Maternal education						
Preprimary or none	103	25.8	55	13.8	158	19.8
Primary	159	39.8	99	24.8	258	32.2
Secondary	113	28.2	185	46.2	298	37.3
Higher	25	6.2	61	15.2	86	10.7
Maternal decision-making autonomy*						
Not practiced	72	18.0	56	14.0	128	16.0
Practiced	328	82.0	344	86.0	672	84.0
Household						
Household SES						
Poor	133	33.2	130	32.4	263	32.9
Middle	135	33.7	134	33.4	269	33.6
Rich	132	33.1	136	34.2	268	33.5
Household food security status						
Unsecure	220	55.0	129	32.2	349	43.7
Secure	180	45.0	271	67.8	451	56.3
Water sources†						
Unsafe	115	28.8	52	13.0	167	20.9
Safe	285	71.2	348	87.0	633	79.1
Feces disposal‡						
Unsafe	236	59.0	172	43.0	408	51.0
Safe	164	41.0	228	57.0	392	49.0
Anthropometry						
Chronic undernutrition in children§						
No	235	58.7	284	71.0	519	64.9
Yes	165	41.3	116	29.0	281	35.1
Birth weight, g						
< 2500	75	18.8	65	16.3	140	17.5
≥ 2500	325	81.2	335	83.7	660	82.5
Maternal chronic undernutrition‖						
No	316	79.0	341	85.3	657	82.1
Yes	84	21.0	59	14.7	143	17.9
Dietary diversity and breast-feeding practices						
Minimum dietary diversity						
Inadequate	164	41.0	119	29.7	284	35.5
Adequate	236	59.0	283	70.3	517	66.5
Breast feeding initiation¶						
Late	235	58.8	188	47.0	423	52.9
Early	165	41.2	212	53.0	377	47.1
Micronutrient supplementation						
Child received vitamin A capsule						
No	128	32.0	82	20.5	210	26.3
Yes	272	68.0	318	79.5	590	73.7
Household use iodized salt						
No	137	34.2	103	25.7	240	30.0
Yes	263	65.8	297	74.3	560	70.0
Disease occurrence						
Child suffering from diarrhea						
No	365	91.3	378	94.5	743	92.9
Yes	35	8.7	22	5.5	57	7.1
Child suffering from ARI						
No	377	94.2	387	96.8	764	95.5
Yes	23	5.8	13	3.2	36	4.5
Health-seeking behaviors						
Child received treatment						
No	240	60.0	205	51.2	445	55.6
Yes	160	40.0	195	48.8	355	44.4
Childhood vaccination coverage#						
Incomplete	114	28.5	49	12.2	163	20.4
Complete	286	71.5	351	87.8	637	79.6

(*continued*)

Table 1 (*Continued*)

Characteristics	Flooded (n = 400)		Non-flooded (n = 400)		Total (n = 800)	
	n	%	n	%	n	%
Indoor pollution						
Types of cooking fuel**						
Unclean	323	80.8	175	43.7	498	62.2
Clean	77	19.2	225	56.3	302	37.8
Cooking practices						
Without separate kitchen	204	51.0	155	38.8	359	44.9
With separate kitchen	196	49.0	245	61.2	441	55.1

ARI, acute respiratory infection; SES, socioeconomic status

*A woman who usually decides by herself or jointly with husband at least on her health care or on large household purchases or visits to family or relative.

†If a home has access to water piped into the dwelling, yard, or plot; public tap or standpipe; tube well or borehole; protected well or spring; rainwater; or bottled water, it is regarded as having safe water sources.

‡If a child uses a toilet or latrine and feces are normally flushed or rinsed into the toilet or latrine or buried, the household is regarded as having safe feces disposal.

§A child is considered chronically undernourished with height for age z score < -2 SD.

‖Maternal chronic undernutrition if body mass index <18.5 kg/m^2.

¶Breast feeding initiated in ≤1 h of birth was considered early initiation,

#Children receiving one dose of bacille Calmette-Guérin; three doses of diphtheria, pertussis, and tetanus; four doses of poliomyelitis; and one dose of measles vaccinations were deemed fully vaccinated.

**Wood; agricultural by-products, residues, and wastes; straw, shrubs, and grass; animal dung; kerosene; coal; lignite; and charcoal were classified as unclean cooking fuels, whereas electricity, liquefied petroleum gas, and biogas were classified as clean cooking fuels.

contributed 19.5%, 10%, 9.8%, 14.8%, and 10 %, respectively, to the total effect of exposure to flood and the likelihood of child chronic undernutrition. Overall, the AORs and their 95% CIs of total indirect effects in the model of exposure to flood and the likelihood of child chronic undernutrition were 1.36 (95% CI, 1.29–1.42) (Table 3).

Discussion

Major findings

To the best of our knowledge, this is the first study in a setting of a developing country to formally examine mediators of the association between exposure to flood and child chronic undernutrition through a complex range of inadequate dietary and breastfeeding practices, lack of micronutrient supplementation, disease occurrence, inappropriate health-seeking behaviors, and indoor air pollution-related practices and to ascertain the extent to which these potential modifiable factors are involved. We came to four important conclusions. First, a considerable proportion of children (35.1%) in our sample data are chronically undernourished. Second, compared with children living in non-flooded areas, children living in flooded areas had a greater risk of having chronic undernutrition. Third, inadequate minimum dietary diversity, a history of diarrhea, incomplete immunization, use of unclean cooking fuel, and lack of a separate kitchen significantly moderate the link between exposure to flood and the chances of child chronic undernutrition. This connection was significantly explained by the identified modifiable factors (79.2%).

Finally, when other sociodemographic, household, and anthropometric factors were taken into account, children whose mothers had a secondary or higher secondary education; children who were <2 y old; children who belonged to middle or rich bands of wealth; children whose mothers did not suffer from chronic undernutrition; children residing in households with safe methods for disposing of feces; children living in households with food security; and children whose birth weight was ≥2500 g had a lower likelihood of experiencing undernutrition.

Comparing the results with previous findings

In this study, in our sample data, > 1 of 3 children suffered from chronic undernutrition, comparable with the results with several other small-scale and nationwide studies in Bangladesh [3–8]. In light of the higher prevalence of chronic undernutrition in children found in our study, researchers and public health practitioners should be concerned that Bangladesh may have significant challenges in meeting the Sustainable Development Goal 2 target of 12% for child undernutrition by 2030 [47].

Our findings point to a connection between child chronic undernutrition and frequent flood exposure, which is in line with some earlier research in other low-resource settings [14–19]. This finding emphasizes how crucial flood exposure is as a risk factor for children's chronic undernourishment in Bangladesh. However, failing to address the heightened risk of child undernutrition in this vulnerable population can gravely jeopardize Bangladesh's efforts to achieve the Sustainable Development Goal 2 target. This study adds new knowledge to the almost untapped areas of the effects of children's nutritional health in flood-prone locations. To reduce child undernutrition in flood-prone areas in accordance with the Sustainable Development Goal targets, a comprehensive multisector emergency response and social development program that involves all concerned organizations and separate relief funds may be necessary. This program could include additional support through income generation and women's empowerment; maternal, infant and young child feeding nutrition campaign; and vouchers that help women and children access health and nutrition services. Additionally, Bangladesh's disaster management agency may get ready to mobilize its workers to offer crucial nutrition services (managing child undernutrition, supplementing food, and micronutrients in flood-affected areas, etc.). All health staff will be taught to be able to respond to the nutritional needs of the population during flood conditions, and the disaster management authority may draft disaster preparedness guidelines to prevent undernutrition after floods.

Our findings were in line with those of earlier studies, which found that children ages ≥2 y [3–5], who belonged to poor bands of wealth [3], whose households did not have safe feces disposal [6], and whose households had unsecured food [7,8] had a higher likelihood of developing chronic undernutrition.

Also in our findings, undernutrition was more likely to occur in children had mothers who had completed only preprimary education or had no education at all [3–5], children whose mothers were chronically undernourished, and children whose birth weight was <2500 g, which is consistent with other studies [6,7].

Table 2
Adjusted odds ratio for associations between exposure to flood; other sociodemographic, dietary, and breast-feeding practices; micronutrient supplementation; disease occurrence; health-seeking behaviors; and indoor pollution−related characteristics, according to child chronic undernutrition (n = 800)

Characteristics	Child chronic undernutrition Adjusted odds ratio (95% CI)	P value
Flood exposure (ref. = no)		
Yes	1.74 (1.53−2.28)	0.002
Sociodemographic		
Child age, mo (ref. = 12−23)		
24−35	2.33 (1.11−4.90)	0.009
36−47	2.67 (1.24−5.74)	0.007
48−59	2.73 (1.27−5.87)	0.005
Child sex (ref. = female)		
Male	0.97 (0.76−1.24)	0.338
Maternal education (ref. = preprimary or none)		
Primary	0.93 (0.83−1.04)	0.221
Secondary	0.76 (0.69−0.84)	< 0.001
Higher	0.61 (0.52−0.70)	< 0.001
Maternal decision-making autonomy (ref. = not practiced)		
Practiced	0.94 (0.61−1.45)	0.279
Household		
Household SES (ref. = poor)		
Middle	0.83 (0.73−0.94)	0.003
Rich	0.68 (0.59−0.79)	< 0.001
Household food security status (ref. = unsecure)		
Secure	0.81 (0.74−0.88)	< 0.001
Water sources (ref. = unsafe)		
Safe	0.86 (0.73−1.02)	0.081
Feces disposal (ref. = unsafe)		
Safe	0.74 (0.66−0.82)	< 0.001
Anthropometry		
Birth weight, g (ref. = ≥ 2500)		
< 2500	1.13 (1.03−1.24)	0.012
Maternal chronic undernutrition (ref. = no)		
Yes	1.91 (1.62−2.25)	0.003
Dietary diversity and breast-feeding practices		
Minimum dietary diversity (ref. = inadequate)		
Adequate	0.78 (0.65−0.93)	0.007
Breast feeding initiation (ref. = late) Early	0.99 (0.87−1.07)	0.454
Micronutrient supplementation		
Child received vitamin A capsule (ref. = no)		
Yes	0.94 (0.87−1.02)	0.165
Household use iodized salt (ref. = no)		
Yes	0.76 (0.53−0.98)	0.012
Disease occurrence		
Child suffering from diarrhea (ref. = no)		
Yes	1.15 (1.03−1.28)	0.011
Child suffering from ARI (ref. = no)		
Yes	1.01 (0.85−1.19)	0.748
Health-seeking behaviors		
Child received treatment (ref. = no)		
Yes	0.98 (0.90−1.06)	0.593
Childhood vaccination coverage (ref. = incomplete)		
Complete	0.87 (0.81−0.94)	0.001
Indoor pollution		
Types of cooking fuel (ref. = unclean)		
Clean	0.83 (0.73−0.94)	0.003
Cooking practices (ref. = without separate kitchen)		
With separate kitchen	0.85 (0.76−0.94)	0.002

ARI, acute respiratory infection; ref, reference; SES, socioeconomic status

The identified modifiable factors, in particular inadequate dietary diversity, were responsible for a greater proportion of the association between exposure to flood and the likelihood of child chronic undernutrition in our study. Humans need to eat a range of foods to thrive, and studies conducted in Bangladesh and other low-resource environments have found that children ages <5 y benefit greatly from a varied diet in terms of their physical growth [23]. Floods influence dietary variety in two ways: first, they diminish or destroy local crops, reducing output, and second, they cause food costs to rise and residents in flood-affected areas to have less purchasing power due to sporadic unemployment and the spread of diseases [23,24]. When the floodwaters have receded in Bangladesh's flood-affected areas, the locals typically choose fields to cultivate [25]. Due to seeds and other farming supplies, they occasionally cannot cultivate. To ensure nutrition and prevent undernourishment, government and non-governmental organizations should step up to assist the badly affected farmers in the postflood period by supplying seeds and materials like fertilizer and equipment.

Numerous research reports from around the world [9−13] have found a connection between diarrheal disease and child undernutrition, which is consistent with the findings of our study. In our

Table 3
Direct and indirect effects (odds ratio scale) in the model of exposure to flood on child chronic undernutrition operating via inadequate dietary and breast-feeding practices, lack of micronutrient supplementation, disease occurrence, inappropriate health-seeking behaviors, and poor living condition ($n = 800$)

Potential mediators	Odds ratio	95% CI	Mediated, %	95% CI
Direct effect	1.09	1.06–1.13	20.8	16.8–23.8
Indirect effect of				
Inadequate dietary diversity and breast-feeding practices				
Inadequate minimum dietary diversity	1.08	1.04–1.13	19.5	15.7–23.8
Late breast-feeding initiation	1.01	0.96–1.03	2.5	0.66–3.6
Lack of micronutrient supplementation				
Not taking vitamin A supplements	1.01	0.97–1.05	2.5	2.4–5.8
No use of iodized salt	1.02	0.99–1.06	5.1	3.0–7.8
Disease occurrence				
History of diarrhea	1.04	1.03–1.07	10.0	8.9–13.8
History of suspected pneumonia	1.01	0.97–1.07	2.5	0.54–3.8
Inappropriate health-seeking behaviors				
Not receiving treatment for childhood illness	1.01	0.97–1.04	2.5	2.1–5.7
Not fully vaccinated	1.04	1.01–1.07	9.8	8.9–14.1
Indoor pollution				
No use of clean fuel	1.06	1.04–1.08	14.8	9.6–14.5
Not having a separate kitchen	1.04	1.03–1.07	10.0	8.8–13.7
Total indirect effect	1.36	1.29–1.42	79.2	76.3–84.4
Total effect	1.48	1.31–1.58		

Model is adjusted for child age, sex, maternal education, maternal decision-making autonomy, household socioeconomic status, household food security status, water sources, feces disposal, birth weight, maternal chronic undernutrition, and marital status; direct, indirect, and total effects are those calculated by Stata binary_mediation command

findings, that a crucial mediator of the link between flood exposure and child undernutrition was a history of diarrheal sickness. One of the most important components of public health security during floods is biological safety. Floodwaters and readily accessible sources of clean drinking water can easily get contaminated with harmful pathogens (bacteria, viruses, parasites, protozoa, and fungi) from the natural and human environment, which raises the risk of waterborne illnesses like diarrhea [12,13]. In order to prevent undernutrition in the flood-affected areas, diarrheal sickness denotes a major need for protective water supply.

It is generally accepted that complete immunization is believed to protect children from infections by boosting their immune systems, which can help them avoid undernutrition [40]. Among the health-related behaviors investigated, it was found that incomplete immunization significantly influenced the relationship between flood exposure and child chronic undernutrition. There are several reasons why exposure to flooding might affect the full vaccination rate. For instance, exposure to flooding is linked to increased diarrhea and other waterborne illnesses; therefore, parents from flood-affected areas may decide against immunizing their sick child out of concern that it will further worsen their condition. The state of household finances could also be an issue. Reduced yields may leave families who depend on agriculture with less money, which might make it more difficult for them to afford transportation to a clinic, or it might cause them to spend more time trying to scrape together enough money to survive. The ability of a parent to balance competing objectives in their lives may be further hampered by mental health issues that arise during flooding and an increase in domestic violence. It is possible that they would not have time to take care of other crucial matters, such as taking their child to medical visits for immunizations. Due to the destruction or deterioration of public health infrastructure and medical facilities, exposure to floods can also have an effect on vaccination rates.

Use of unclean cooking fuel [9,10], which significantly mediated the association between flood exposure and child chronic undernutrition, was of special significance in the indoor air pollution behaviors investigated. Food is cooked in a traditional cooking stove using biomass fuels, such as wood; agricultural by-products, residues, and wastes; straw, shrubs, and grass; animal dung; kerosene; coal; lignite; and charcoal in Bangladesh's flood-prone areas, because liquefied petroleum gas and biogas are not readily available [30]. Although the exact mechanisms by which exposure to unclean fuels causes undernutrition in children are still not fully understood, it is thought that they play a role in the pathogenic processes associated with toxic pollutants, inefficient burning, and combustion-generated gases and particulate matter [30]. According to the findings, policymakers should design efficient interventions to hasten the switch from unclean cooking fuels to cleaner energy in flood-prone areas to lower the prevalence of child undernourishment.

Evidence suggests that having a separate kitchen lessens [39,40] the likelihood of childhood undernourishment by reducing the effects of solid fuel burning. In our findings, having a separate kitchen was a significant mediating factor in the relationship between flood exposure and chronic undernutrition in children. According to research, floods can have a significant effect on housing and households. Most homes in Bangladesh's flood-prone regions are constructed using "mud walls, coconut leaf walls, and tin walls." These kinds of homes are susceptible to being washed away by swift flood waters, leaving a huge number of people stranded and homeless for days. They lack a separate kitchen for cooking as a result. Additionally, some people who reside in buildings experience physical damage from floods, making it impossible for them to have a separate kitchen.

Strength and limitations

This study had three significant strengths. First, this was the first study to formally examine factors mediating the association between exposure to flood and the likelihood of child chronic undernutrition through a complex range of dietary and breast-feeding practices, micronutrient supplementation, disease occurrence, health-seeking behaviors, and poor living conditions. Second, we used standardized and consistent methods to measure height and weight across all children; therefore, the measurements are reliable and can also be compared with other populations. Third, we have considered repeated exposure to flooding effect, which is likely to pose an even greater risk to child undernutrition than single periods of exposure.

There are some limitations in this study. First, data used in the analysis were cross-sectional; therefore, the results did not allow us to discuss longitudinal mediation mechanism. The cross-sectional results do not provide information on directions of the relationship; therefore, causal mechanisms are not yet answered. Second, we used purposive sampling—which does not use random selection—to choose the households where the children were residing, because there was no household list available in the flood-affected areas. This means that generalizing from the sample to the population is not possible, because the sample we collected is probably skewed and does not accurately represent the population. Furthermore, although union selection is involved, we neglected to account for the design effect while calculating the sample size. These are important elements to keep in mind for our future study. Third, our estimates may be biased due to selective survival. If this is the case, we are likely to underestimate the effects of flood exposure on child undernutrition. Fourth, this study did not include other relevant conditions related to undernutrition, such as coping mechanisms, which may have an effect on this association. Fifth, most of the data used in the analysis were self-reported. Although, the results should be carefully interpreted assuming potential recall bias, the analyses were performed based on the assumption that there are reasonably accurate estimates of adherence by self-reported questionnaire. To minimize recall bias, face-to-face interview methodologies, instead of self-administered questionnaires, were applied for their answers.

Finally, household wealth was evaluated indirectly by developing an asset-based index, because of insufficient reliable household economic indicators across households of all social categories in low- and middle-income countries. An asset-based index is mostly treated as a decent proxy for house economic standing.

Conclusions

The present study added to the body of evidence linking exposure to floods and child chronic undernutrition in finding that inadequate dietary diversity, a history of diarrhea, incomplete immunization, the use of unclean fuel for cooking, and lack of a separate kitchen are all pathways between flood effect and the likelihood of child chronic undernutrition. These modifiable factors offer useful data when designing interventions to lessen the effect of floods on child undernutrition in Bangladesh. Future longitudinal research by following a cohort will provide information to discuss the mediators influencing the relationship of exposure to flood at the baseline and child undernutrition in the follow-up phase.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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